


6-1-1938

A Study on the Origin of Banded Agate

James E. Driscoll

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A STUDY ON THE ORIGIN OF BANDED AGATE.

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by

James E. Driscoll

A Thesis

Submitted to the Department of Geology
in Partial Fulfillment of the Requirements
for the Degree of
Bachelor of Science in Geological Engineering.

Montana School of Mines

Butte Montana

June 1938

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STUDIES ON THE ORIGIN OF BANDED AGATE

By James E. Driscoll

INTRODUCTION

The Problem - Agate in any of its varieties presents numerous problems in regard to its origin. Many types have been described and their beauty elaborated upon, but little has been written concerning their formation and the problems involved. The genesis of agate implicates an amazing complexity of physical and colloidal chemistry, as well as, various principles of geology. It is the purpose of this thesis to scrutinize the acceptable theories on origin, and, if possible, to adapt one which will fit the observed facts. Because of the limited availability of agate localities the author has confined detailed study to the South Boulder Canyon district about twelve miles southeast of Whitehall, Montana.

Historical Note - Some forms of agate have been known since the dawn of history, and historically it has enjoyed long usage both as tool and gem; but not until the nineteenth century was its formation seriously investigated (15). The first written record of agate was made by Theophrastus about 300 BC, who named it from the river Achates in Sicily. Haidinger, a German geologist, offered the first feasible theory on origin about 1849. His contemporary, Noggerath, presented a variation of the theory somewhat later. Bauer, about 1900, wrote a more detailed account of the formation of agate patterned after the existing ideas.

Then, in the following ten years, R. E. Liesegang advanced his discoveries with colloids as an explanation of agate formation (17,18). Although this theory is generally accepted as the best explanation of agate genesis, there are many problems about which very little is known.

Acknowledgements - In the preparation of this paper the author is indebted to the Geology Department of the Montana School of Mines, especially Dr. E. S. Perry whose advice and help have made the problem easier, and to Dr. A. E. Koenig of the Chemistry Department. In addition, the author wishes to thank all those who have rendered help in any phase of this thesis.

TYPES OF AGATE

Definition - Broadly speaking, agate is a variety of quartz. More specifically, it is a variety of chalcedony distinguished by its banded structure and color. It is cryptocrystalline with a composition of nearly pure anhydrous silica. It is very tough, and has a hardness of about seven. These properties, combined with pleasing patterns, make agate useful for ornamental purposes.

Common Types - Based chiefly on pattern, the following classification describes the well-known types of agate.

Ring or eye agates are those which are made up of nearly circular concentric bands of different colors.

Fortification agates are those agates which have bands and

arranged in curving contours and salient angles. They resemble an old time bastion.

Clouded agates are irregularly and obscurely colored, and are poorly banded varieties.

Pipe agates are those, which, in cross section appear to be made up of numerous pipes or tubes all cemented together, consist of stalactitic growths.

Ribbon agates show straight parallel bands and are often called onyx but should not be confused with certain banded shales which are commercially called onyx.

Enhydros is an agate which has a hollow center and usually containing a liquid or gas.

Fragments of agate cemented together with chalcedony are termed ruin or brecciated agate.

When certain agates containing bands so fine and close together that when properly ground they will disperse the light into the prismatic colors they are called rainbow or iris agate.

Moss agates are those which contain inclusions of material in a dendritic form thus resembling moss and trees.

When moss agate contains a group of dendritic growths which yield themselves to an imaginative landscape scene the term scenic or landscape agate is applied to them.

Forms related to Agate - In addition to the above there are several substances which are similiar to agate.

Agatized wood is petrified wood in which the replacing

mineral is cryptocrystalline quartz or chalcedony. If the replacing mineral is amorphous hydrous silica the result is opalized wood.

Opal is a strictly amorphous variety of quartz having a certain amount of water in its composition. Opal is much softer than agate, seldom if ever forms banding, and with time, it is believed, crystallizes into chalcedony.

Flint is chalcedony which formed as concretions in limestone. Occasionally it exhibits rude banding. Jasper is an opaque red or orange colored chalcedony formed as concretions, replacements, and fissure fillings, the color being due to ferric iron. Heliotrope is a chalcedony containing iron in the ferrous condition, resulting in green colorations. When heliotrope contains red specks of jasper the product is called bloodstone.

Agate like banding has been observed in numerous natural substances. For instance, granite, rhyolite, sandstone, shale, and ore deposits are sometimes banded, usually by ground waters and iron stain. Travertine often resembles agate, being similar to onyx in structure.

THEORIES OF FORMATION

Agates are known to be formed in rock cavities. Most of these cavities are gas bubbles or blow holes in volcanic flows formed by the expansive forces of gases and vapors within these rocks when they were molten. Other cavities, such as those produced by the decay of wood, are also subject to agate deposition. Theories of formation have been concerned with the manner of deposition of silica in these cavities to produce

banding. The following are the important theories.

Haidinger (7) - The German geologist, Haidinger, made the suggestion in 1849 that the moisture ordinarily found in rocks would "sweat" through to the cavities, and that intermittent influxing of silica-bearing solutions would thus enter the cavity through diffusion and deposit successive layers of agate. In opposition to this idea agate cutters point to the fact that the outer layers of agate are the toughest and that the first few layers would prevent the diffusion of more solution. In support of the idea it may be well to mention that toughness is not a function of the porosity, and that the agates can be dyed by a diffusion process, thus showing that the substance cannot be sealed to the molecular migration of solutions.

Noggarath (7) - Haidinger's contemporary, Noggarath, doubting the possibility of diffusion to produce banding, pointed out the existence of what appears to be canals in certain agates and suggested that these might be conduits by which solutions percolated back and forth during the formation of the agate. Many objections arose to this idea however, because although some agates do contain apparent channels most evidently do not, and even though one did exist it seems improbable that it remain open after the first deposition of silica gel, if such were the original form of the mineral matter. An even more convincing argument against the theory is that there is no evidence of channels in the hard dense host rock.

Bauer (4) - Bauer tried to explain the formation of agate by the channel idea under conditions of hot intermittent springs. He endeavored to show that a delicate balance of non-continuous flow, such as Yellowstone Park geysers, would saturate the rocks and then sink again leaving the rocks dry for a period. The cavities would fill up with hot water bearing a little silica and then empty again, but leaving a film of solution on the walls which would dry and deposit a thin layer of silica. The conduits would be kept open by the frequent recurrence of solution, depositing only a very thin layer and this each time drying. Assuming that an elusive channel exists in every agate, the main objection to this theory is that the solutions would contain other materials than silica which would also deposit on the walls when dry.

Liesegang (1,7,17,18) - The most recent theory on agate genesis has been advanced by R. E. Liesegang, a German chemist and geologist, who offers a radically different idea. According to this theory the rock cavity becomes filled with silica in a colloidal condition; a colloidal particle is thought to consist of about one hundred molecules and is fine enough to pass through most filters. Upon losing part of its water the mass becomes a gel which is subjected to diffusion by a metallic salt, and by a process of rhythmic deposition of a precipitate produces banding. This phenomenon was demonstrated in the laboratory by Liesegang with artificial gels. Liesegang later recognized two kinds of diffusion in agates; centripetal which proceeds inward from the

walls, and centrifugal which proceeds outward from the core. Besides explaining the banding this method of formation also indicates why agates are sometimes hollow in the center. Drying of the colloidal silica gel causes a shrinkage of the bulk which contracts to the walls leaving a cavity in the interior of the nodule. Also, this theory asserts that the frequent occurrence of crystals in the interior of a cavity is due to the relief of surface tension when the gels dries. Crystals cannot form in colloids on account of the surface tension but when this tension is relieved complete crystallization can take place. Although fortification agates can be conceived by this method of formation, pipe and moss agates are difficult to account for in this way. Objections to this theory are that some cavities are completely filled with chalcedony with no evidence of shrinkage, that banding is present often without the apparant presence of impurities, and that channel like patterns do exist in some agates.

In general this theory can be molded to fit almost any type of agate, and, with slight modifications, can be made to apply to every case with which the author is familiar. The remainder of this thesis shall be devoted to the review of the author's observations on hand-specimens and thin sections, and the interpetation of certain apparantly non-conforming cases.

THE SOUTH BOULDER DISTRICT

Occurance of Agate

In Montana, as elsewhere, agates are likely to be found wherever there are amygdaloidal lavas. Amygdaloidal lavas are a part of nearly every volcanic flow, especially andesitic flows. The weathering of lavas releases the agate nodules which then become pebbles in the beds of streams. The Yellowstone River valley has a series of gravel benches each containing vast numbers of agates. The stones, by some process taking place in the bed of the stream, have been subjected to the growth of dendrites producing moss agates. (See Plate 6 B,C,D). In the South Boulder District the agates are still in place or nearly so. Most of the author's raw material was procured from this area, because it provided a convenient and abundant supply of both agate and host rock.

General Geology

Located about eight miles up the South Boulder Canyon from the Jefferson River are a series of andesite lava flows of either Tertiary or Cretaceous age. The flows dip about twenty degrees to the South, up the Canyon, and, although the area is in the trough of a syncline, they probably rest at their initial inclination. (See Plate 1 B,C). One of these flows is dubbed "oatmeal lava" because it contains flat phenocrysts of light colored plagioclase in a fine grained matrix (See Plate 4). It is exposed only in a small area of which certain portions

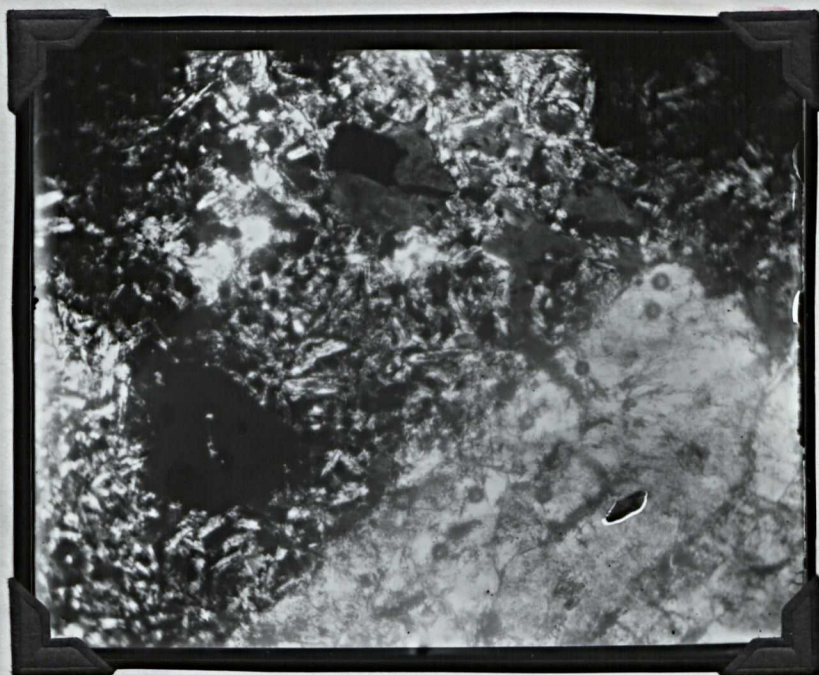
are amygdaloidal and bear large quantities of agates. Adjacent to the major agate zone are a series of fissures which are filled with large quantities of heliotrope and some red jasper. A small displacement has brecciated the fissure filling and the pieces have been cemented together by calcite. The wall rock is extensively replaced by the heliotrope and some of the vesicles are filled with the material. Rude banding is apparant in the amygdules of heliotrope and the center is commonly spattered with red jasper. The fissures also show this variation from the ferrous iron to the ferric iron state; the center of the gashes being orange jasper bordered with red jasper, and the wall contant being green heliotrope.

One of the basal flows of the series, about two miles up the canyon, is a vesicular lava which is quite extensive in outcrop and carries numerous small agates (See Plate 6). The flow is fine grained so that the vesicles are smooth and regular.

Character of the Host Rock

Under a magnification of approximately one hundred diameters "the oatmeal" rock shows well-formed phenocrysts of plagioclase in a fine grained matrix (See Plate 1,A). The large phenocryst of feldspar at the lower end of the view is somewhat weathered and broken in appearance. The characteristic trachitic texture of the fine grained andesite may be seen in the upper part of the picture, along with large pieces of black magnetite and dark blotchy areas of green chloritized plagioclase. In some

PLATE I



A

Photo-micrograph of thin section of andesite porphyry
("oatmeal lava") from South Boulder - X100 - plane polarized light.



B

C

Eastward view of the outcrop of the (darker) "oatmeal" rock.

areas small grains of chlorite have crystal outlines, indicating that a ferromagnesian mineral has been replaced. No ferrmagnesian minerals can be seen in the photograph in Plate 1. A few grains of zircons are scattered through the rock. The plagioclase has the approximate composition of laboradorite. The technical name for the lava is porphyritic andesite.

Character of Agates

The nodules of agate gathered from the South Boulder area vary from the size of a small pea to about five inches in diameter. The majority are about one inch in diameter. They have extremely irregular shapes and rough walls as if the host rock partly collapsed before solidification. A large proportion are elongated, not like the typical almond shaped amygdule, but like a rough short piece of pipe. Others are pillowy with a flat base and an even dome.

The four specimens shown in Plate 2,A are typical agates of the South Boulder district. The banded ones on the right hand side of the photograph are particularly fine in that they are completely filled with agate. The dark specimen is inconspicuously banded towards the center, but the bands are numerous and very fine. A similiar dark agate gave a test for manganese when analysed microchemically. The lower right hand specimen consists of alternating bands of opaque and clear material. It has no inclusions and is flawless. The agate in the lower left corner is similiar to about fifty percent of the nodules to be

PLATE 2



A

A typical group of South
Boulder agates showing various types of
banding - natural size

found in the South Boulder agate locality, in that they have very irregular banding and a center of crystalline quartz. Another noteworthy point is the compression of the center of banding against one side, with a widening of the bands in the opposite direction. This fact is noticeable in nearly every case. The presence of stalactitic-like growths from the walls is also true of nearly every agate, and is particularly exemplified in the lower right hand specimen. The term "stalactite" is used in agate study to designate long narrow protuberances from the walls extending toward the centers, and around which agate banding wraps itself. This may be an indication of the original orientation of the agate as in place in the host rock.

The upper left hand nodule is representative of about forty percent of the cavity fillings. It has a wall lining of agate and then a nearly solid filling of coarsely crystalline quartz. A crystal of calcite, evidenced by a cast, existed within the nodule, and must have formed before the crystallization of the quartz. Calcite is a common constituent of South Boulder agates.

Unusual Agates - The three members of Plate 3 depict a few of the unusual agates of the South Boulder district. They are shown enlarged about two diameters in order to bring out the details. The top agate besides showing an excellent display of stalactites also exhibits a crystal cast at its base. The cast is unquestionably that of calcite. The unusual feature is that it occurs in contact with the wall rock instead of

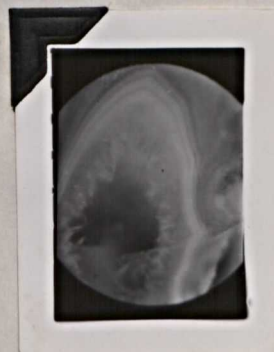
PLATE #3



A



B



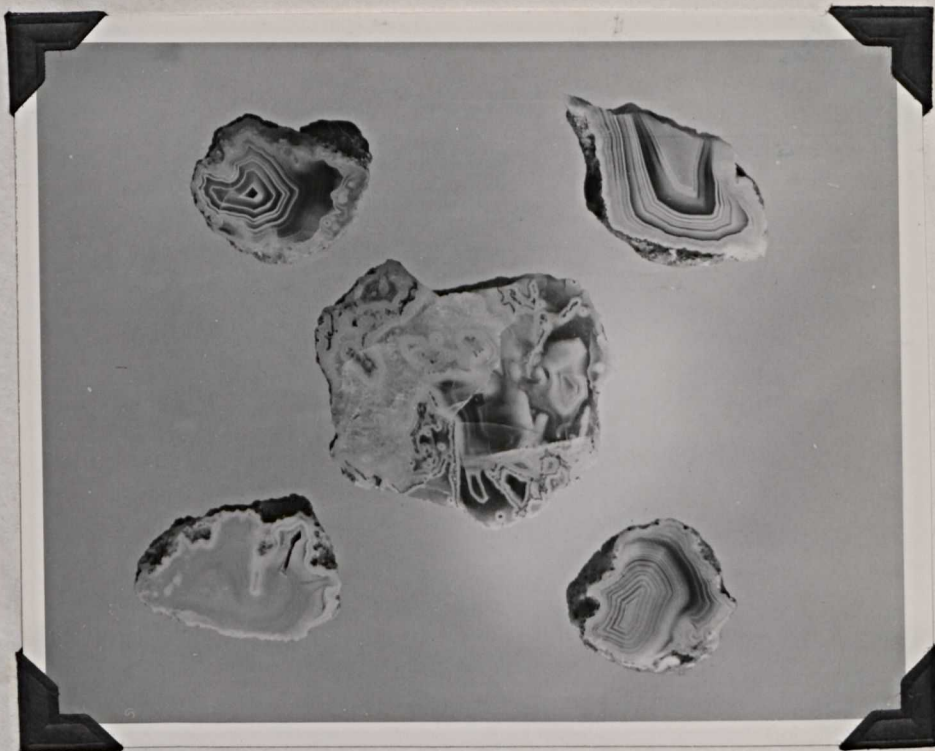
C

Unusual agates from the South Boulder Canyon - X2

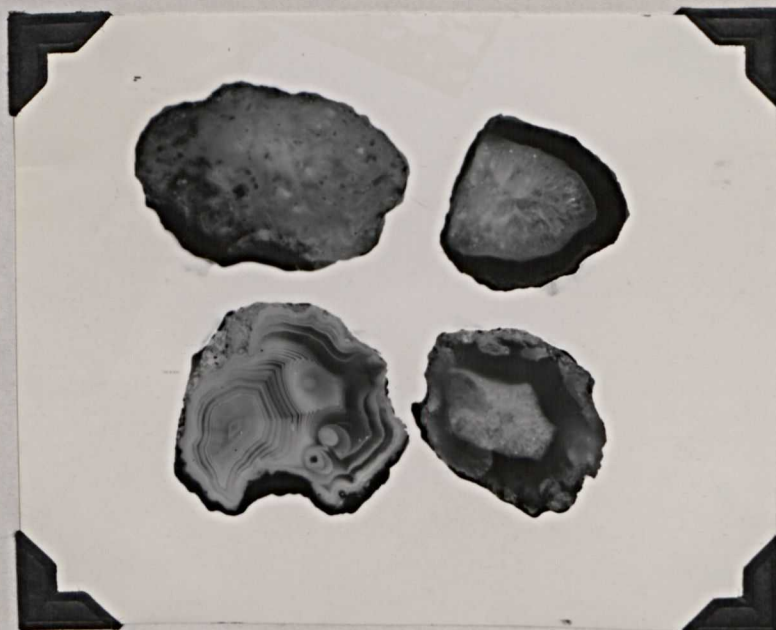
within the nodule. The banding of the agate sweeps around both the stalactites and the crystal cast as if later in age. In the lower right hand corner is shown an agate with a coarsely crystalline quartz band showing "comb structure", but instead of being hollow, as the majority are, it has a second stage of agatization completely filling the earlier geodic nature of the hollow. The inner filling has no banding apparant to the naked eye. The lower left member of the group very effectively displays, even in the photograph, an orientation of the bands so that a wedge-like reflection of the light results. On the face of the remaining half of this same agate so-called channels cut the banding and appear to connect the exterior with the interior (Plate 3, B). Although this type of structure is called "channel" in agate studies, in reality it is dense cryptocrystalline quartz similiar to that of other parts of the stone. Plate 3,c shows an enlargement of the comb structure of the agate in figure A.

Of the group of agates shown in Plate 4,A, special attention is called to the center member. The specimens are reduced in size about one third. The large section shows an amazing confusion of banding and crystalization. The bands weave back and forth as if the original material had shifted while the engulfing medium was in a plastic condition. The lower left hand member has a well developed stalactite in the center which is composed of opaque agate with a narrow seam of iron stain along the axis. To the right of the stalactite is a small long void

Plate 4



A



B

Some Varieties of South Boulder Agates

(black in photograph), which has agate banding sweeping around it with no evidence of crystalline filling. The upper left hand specimen shows how the banding may not extend clear to the outside. This view is near the end of an elongated nodule.

The specimens shown in Plate 4-B illustrate some variation from the normal type of South Boulder agate. The specimen in the upper left corner is a greenish colored unbanded nodule. It consists of clear agate thoroughly mottled with a ferrous iron impurity. The specimen in the upper right corner has a border of red jaspery agate with a coarsely crystalline quartz core. In the lower left corner is a well banded specimen showing a cross-section of stalactite or pipe like structures which carry red colored impurities into the interior. The agate in the lower right corner is similiar to the specimen above it except that the agate border is clear and unbanded.

In Plate 5 is shown an excellent example of stalactites within a cavity. Although the particular stone pictured is from the vicinity of Red Lodge, Montana, it exemplifies the structures which are often noted in South Boulder agates. The growths within the pictured specimen are coated with quartz crystals on the surface, and instead of consisting of chalcedony are coarsely crystalline quartz, with the hollow axes which are so characteristic of stalactites. The South Boulder agates, in contrast to the pictured specimen, have extremely small growths, even microscopic, which are enveloped by and consist of chalcedony. The Red Lodge specimen, like South Boulder agates, contains some calcite crystals.

PLATE 5



Quartz Stalactites within a Geode
from Red Lodge, Montana - slightly reduced

The Effect of Impurities - The reaction of impurities on agate formation is not readily determineable, but their effect is constantly noted. Complications, as the result of different constituents and concentrations, must certainly take place. It was observed that the quantity of calcite in a nodule was in a ratio with the amount of quartz crystalization, the degree of crystalization increasing with the calcite content (See Plate 6 A). However, exceptions to this were also found.

Moss agates, it is noted, owe their dendritic growths to a manganese impurity which apparently penetrates by diffusion subsequent to solidification and probably subsequent to their deposition in stream gravels. This is brought out by the fact that cracks and flaws are favored by the dendrites, and especially are the initial bands of the stone subject to the growth of dendrites. (See Plate 6 - B, C, D,).

The upper specimen in Plate 6A shows a siliceous nodule in place in the host rock of "oatmeal lava". The filling contains small fragments of wall rock as an impurity. The silica, which occurs in large fragments, is honey-colored and clear, almost opalitic.

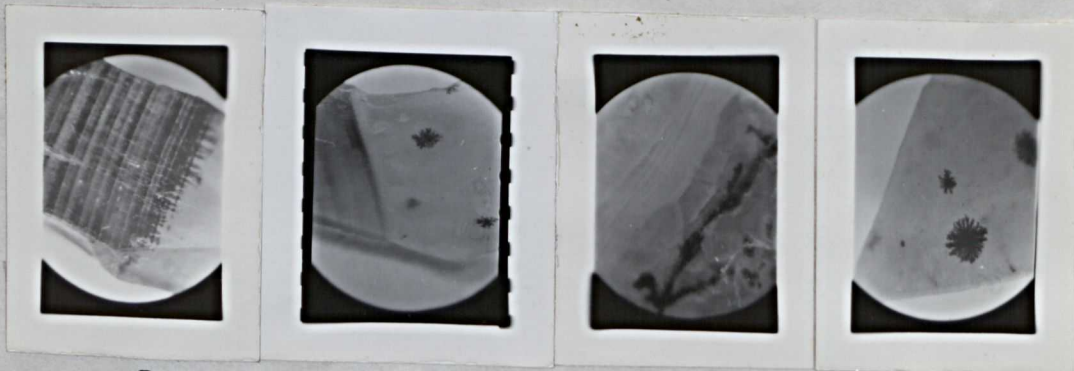
The lower specimen is an example of calcite within the central part of a cavity filling. The quartz, which constitutes the remaining portion of the filling, is amythestine toward the center and grades into finer grained material toward the outside. A thin lining of agate makes up the walls. The notable factor is that the calcite is perfectly crystalized within quartz crystals.

PLATE 6



A

Some Siliceous Fillings



B

C

D

E

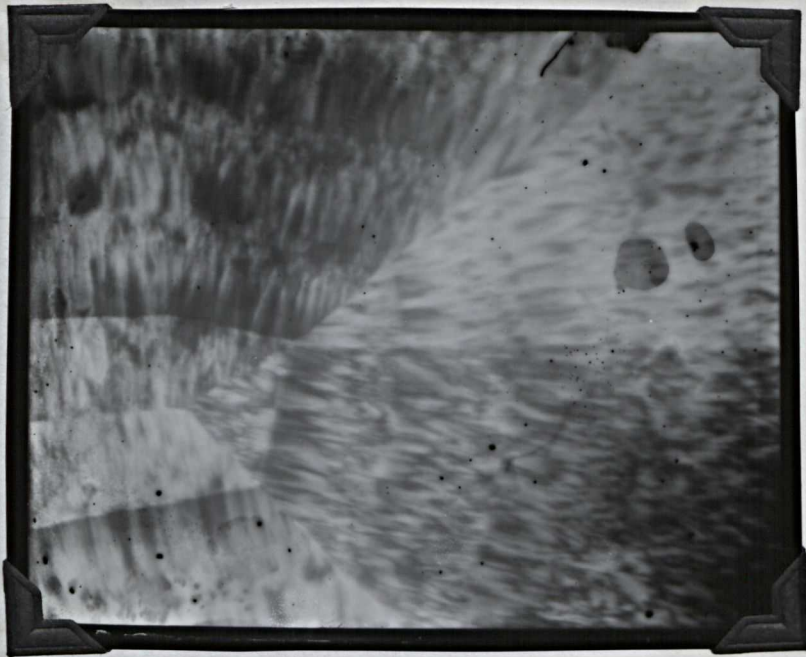
Dendrites in Moss Agates, from Yellowstone River Valley - X5

Thinsection of Agate - The pictures shown in Plate 7 were taken under a magnification of one hundred diameters and under crossed nicols. The top picture was taken near the center of the agate and the lower one near the outer edge. The wedge structure due to the orientation of the microscopic quartz crystals can be seen in the top figure. The bands appear to consist of larger quartz crystals oriented at right angles to the bands. They apparently rest on a flat base and terminate outward from the center. The spherulitic pattern (B) is due to a pipe like structure.

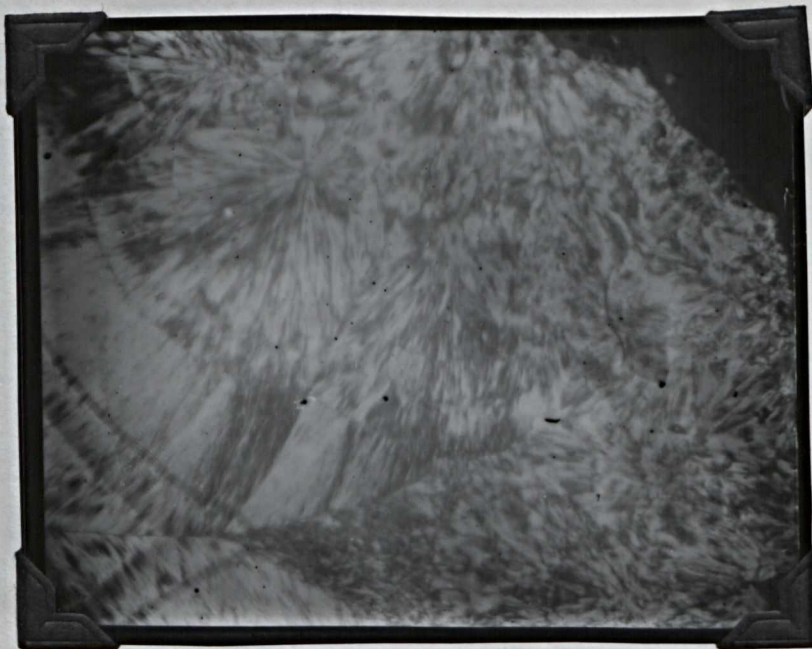
Vesicular Lava- A typical piece of amygdaloidal lava is shown natural size in Plate 8. The original vesicles were smooth walled, characteristically almond shaped, and varying in size from a pin-head to about a half inch in length. The matrix is fine grained unaltered andesite. A few small phenocrysts of ferromagnesian minerals may be seen with the naked eye. The vesicles are in all stages of filling. Those which are completely filled exhibit a zoning or crude banding, not always concentric, and show no evidence of shrinkage (See Plate 8 B). A group near the lower right hand corner are lined with drusy quartz. Some, as represented by a vesicle near the center, completely lack silicification and instead contain a black powder which becomes magnetic upon heating.

The vesicles were formed by gas, probably expanding steam, when the lava was molten. The cavities subsequently became subject to deposition of material by ground water after cooling and burial of the lava mass. Because of the compactness of the

PLATE 7



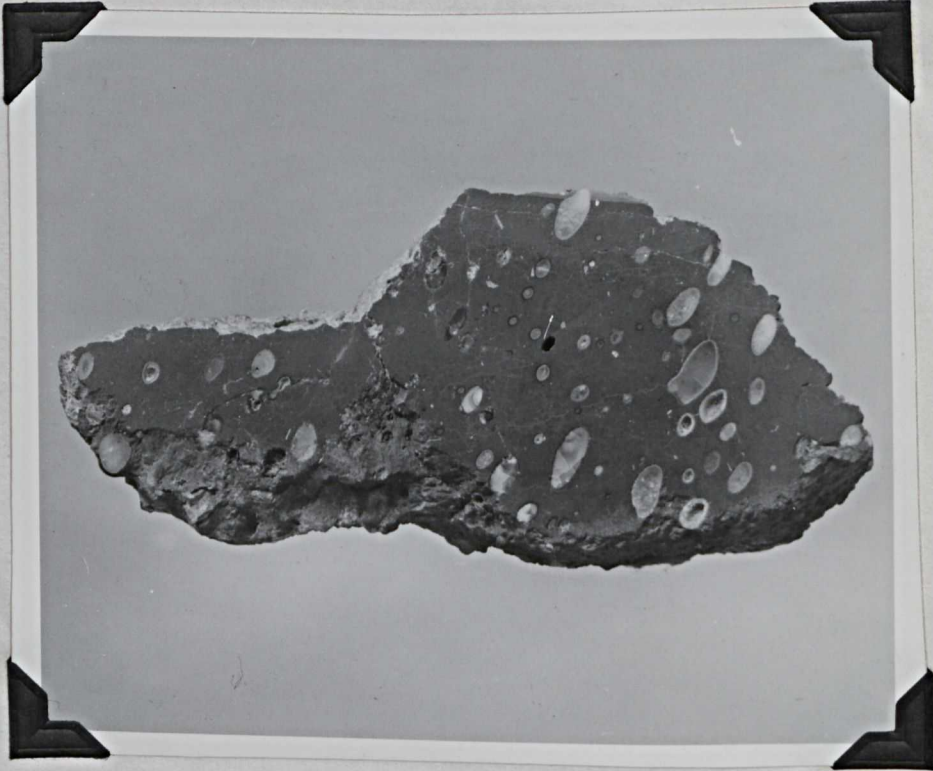
A



B

Photomicrographs of Agate Thinsections, - X 200, crossed nicols

Plate 8



A



B

Vesicular Lava

rock, migration must be thought of as intermolecular. Ground waters carry variable amounts of dissolved silica, and silica has a tendency to form colloidal particles, incapable of migration through molecular spaces. Thus when voids are encountered by the waters the silica has a chance to form a colloid which cannot move out. The colloid collects and forms a gel which subsequently dehydrates and hardens into agate. Iron compounds are also carried by ground waters and the black powder in the agate free voids may be the precipitated loads of such waters. Two questions arise; why are the silica and the iron oxide not intimately associated, and if there were two solutions at different times - one for iron and one for silica - why are some vesicles favored by silica and some by iron. The answers to these questions are not apparant, but the author believes that some unrecognized physical-chemical factor is responsible.

CONCLUSIONS

From the above observations is concluded the following sequence of events in the formation of banded agates.

A vesicular lava becomes buried and inundated by ground water. The ground water decomposes the constituents of the rocks in the beds or brings in dissolved matter from the surrounding formations. The dissolved matter consists of silica, iron salts, manganese salts, and calcium carbonate. The vesicles of the buried lava become filled first with water containing the dissolved matter and later as the concentrations become high enough the silica forms colloidal particles which are then trapped in

the cavity. The other soluble constituents never become concentrated but are carried away as fast as they are formed. The silica, in the meantime, starts to form a gel. The gel gradually loses its water and adheres to the walls which produces a void at the center due to shrinkage. This cavity usually traps a little solution containing lime and other salts. Sometime during the process of solidification a banding takes place according to Liesegang's fashion of rhythmic precipitation. The material for precipitation comes from the normal metallic salt content of the ground water and takes place by diffusion. If the diffusion is from the walls inward centripetal banding results: if the diffusion is from the trapped solution at the core centripetal banding takes place. If a constant supply of silica is available the cavity may become entirely filled because the gel is replenished with more silica as fast as it shrinks. But if the solidification has taken place the further influx of silica results in the crystallization of quartz at the core. Next comes a long process of ageing during which time the gel crystalizes into submicroscopic crystals. The precipitant in the bands has some sort of catalyzing effect on crystallization so that the crystals here grow faster and hence larger. It is difficult to say when the process ceases. Very likely it proceeds indefinitely until the agate becomes completely filled and grows quite coarsely crystalline.

- - - - -

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